Amended specification, page 2

Description

Method and electronic device used to synthesise the sound of church organ flue pipes, by taking advantage of the physical modeling technique of acoustic instruments.

The present patent application refers to a method and electronic device used to synthesise the sound of church organ flue pipes, by taking advantage of the physical modeling technique of acoustic instruments. Numerous numerical algorithms of physical-mathematical models have been developed based on the examination of the physical behaviour of organ flue pipes and te sound they produce, in order to synthesise the sound emission of aerophone instruments in real time. ~~Some of these~~ These models are based on the mutual symbiotic interaction between a nonlinear active section, generally defined as "excitation", and a linear passive section, generally defined as "resonator". ~~An example can be found within the method described in US patent 5,521,328.~~ The relative numerical algorithm extemporarily produces a sequence that represents the sound of the instrument analysed and translated into a physical model. The sound is characterised by an initial time interval, defined as "attack transient", during which intensity increases up to a certain value. The intensity value is indefinitely maintained over time during the second phase, defined as "sustain phase", during which the waveform is approximately periodic. The analytical characteristics of this waveform, of which the most important is fundamental frequency, depend on each of the parameters that regulate the operation of the numerical simulation. Being the simulation performed in the time domain instead of the frequency domain because of the presence of numerous non-linear functional blocks, the relation

between the set of parameters and each spectral characteristic of the generated sequence is extremely difficult to establish a priori.

The characteristics can be altered by changing the set of parameters,

Amended specification, page 3

often empirically, and then evaluating the effect of such a change a posteriori, in particular, the fundamental frequency also depends on the quantitative characteristics of excitation, and not only on the frequency response of the resonator, being the evolution of the sequence extremely chaotic during the attack transient phase, the phase of the fundamental frequency cannot be pre-determined once the sustain phase has been reached. These two peculiarities are unacceptable in high-polyphony electronic musical instruments, such as church organs.

~~Other physical -mathematical models, as the invention described in US patent 5,587,648, are based on the conjunct usage of PCM audio synthesis and physical - mathematical simulation of parts of the instrument to be reproduced. By analytically decomposing the sound samples of the instruments to be irritated (or of parts of them, as the only resonant body), and dividing what can be easily and cheaply simulated from what is more convenient to store as part of a wavetable, a good compromise between memory usage and computational power necessary to implement each method can be obtained. The excitation sequence, which is preprocessed by the algorithm which simulates part of the acoustical behaviour of the instrument (previously analyzed and mathematically interpreted), is usually stored as a wavebable. However, said method, though requiring computational power for the physical - mathematical simulation, implies to sample, analyze, and pre-compute the sound of each instrument to be reproduced, and said instrument's reproduced sound is in any case bound to said operations, and in particular to what is stored in the wavetables.~~

The present invention consists in an audio-digital synthesis system based on digital signal processors, which contains a programme of physical simulation of the sound generation of organ flue pipes. The

programme is divided into three fundamental, conceptually independent sections: the first section generates the harmonic part of the sound; the second section generates the aleatory part of the sound; the third section processes these components by means of a transfer function with two inputs and

Amended specification, page 4

one output, thus obtaining the sequence that represents the sound of the organ pipe. Because of the independence of the section that generates the harmonic part of the sound, the fundamental frequency and the phase of the whole waveform generated by the programme can be determined a priori.

The numerical parameters of the simulation programme are partially contained in a static memory and partially obtained by processing information from an electronic musical keyboard and from a set of user controls in real time. They determine the fundamental characteristics of the generated sound, among which the main characteristics are pitch, intensity, time envelope, harmonic composition and aleatory component. ~~Being not any information derived from real musical instruments' sounds and stored as wavetables, memory usage is quite restrained.~~

For major clarity the description of the method and device according to the present invention continues with reference to the enclosed drawings, which a re intended for purposes of illustration only and not in a limiting sense, whereby:

- Figure 1 shows a realisation of a digital electronic musical instrument used to synthesise sounds of musical instruments by taking advantage of the physical modeling technique of the invention.
- Figure 2 shows the three fundamental functional blocks and relative interconnections of an audio digital synthesis programme of the sounds of church organ flue pipes according to the invention.
- Figure 3 shows a flow chart that explains one of the three blocks of Fig. 2, according to which a sequence that represents the harmonic part of the sounds of church organ flue pipes according to the invention is generated.

- Figure 4 shows a stable realisation of a digital harmonic oscillator with two status variables according to the invention.
- Figure 5 shows a procedure used to generate the time variation of the operational frequency of the harmonic oscillator shown in Fig. 4 according to the invention.

Amended specification, page 12

the inputs of the resonator (12) illustrated with details in Fig. 15. The functional blocks of the network (12) form a cycle of operations, along which a sequence of samples propagates for a potentially infinite time. The two contributions of the two generators (9) and (11) are added t this sequence, instant by instant in the sum nodes (46)and (438) nodes, respectively, to sustain the energy of the computed sequence. The structure of Figure 15 is the translation into a mathematical model of the resonant part of the organ flue pipe, defined as "pipework". In particular, the low-pass filter (47) emulates the dissipation of acoustic energy, with variable intensities in function of the frequency; the high-pass filter (49) attenuates all the frequency components lower than the fundamental frequency; by means of the product (51), the envelope generator (50) produces a signal that represents the time progression of the loop gain of the resonant system; the filter (52) alters the sequence phase, leaving its module unchanged; the factor TFBK (53) depends on the type of acoustic termination at the top of pipework; finally, the delay line BDELAY (54) considers the time needed by an acoustic pressure wave to cover the pipework from the base to the top and vice versa. the time progression of the signal produced by the envelope generator (50) is traced in Fig. 16: likewise the envelope of Fig. 13 upon a "note on" event, the signal passes from a value FBL0 to a value FBL1 in a time FBT, and then remains constant. The output sequence (13) is the signal emitted by the mathematical model of Fig. 2 as a whole, that is to say the time representation of the sound emission of the organ flue pipe. The description continues with the original innovative characteristics of the audio digital synthesis technique of the sound of the flue pipes.

the literature on the generation of sounds of instruments with continuous sound emission, among which aerophone instruments, by means of the physical modeling technique, proposes solutions based on a mutual interaction between a non-linear active part, normally defined as excitation (55), and a linear passive part, defined as resonator (56), according to the scheme of Fig. 17. ~~The method exposed in US patent~~

Amended specification, page 13

~~5,521,328 can be considered as an example of this technique.~~ In the case of aerophone instruments, the energy contributed to the system is in the form or sound pressure and the signal produced is the progression of the sound pressure wave irradiated by one or more suitable points of the resonator. The waveform (p(t) is the progression of the air pressure that the performer (or the bellows, in the case of a church organ) exercises on the instrument mouthpiece. According to this progression and to the progression of the pressure w(t) in a suitable point inside the resonator, an oscillating acoustic pressure e(t) injected in the resonator is generated. Once the sustain phase has been reached, the pressure e(t) has the same fundamental frequency as the pressure w(t). Being linear (except for very special operation modes), the resonator can be described with an impulse response r(t), which generates the return signal w(t) and an impulse response h(t), which generates the output signal y(t). The latter is the time progression of the sound emission of the instrument. Being it a numerical simulation performed in the time domain instead of the frequency domain, the fundamental frequency of the oscillation on which the system stabilises, once the sustain phase has been reached, is extremely difficult to predict mathematically. This depends on the fact that the frequency depends on the time progression of the forcing signal a(t), and not only on the frequency values in which the amplitude spectrum of the impulse response of the resonator has the relative maximum values. In fact, any type of harmonic oscillator (electronic, mechanical, etc.) has this characteristic. With regard to wind instruments (including organ pipes), it is sufficient, for example, to increase the sound pressure to obtain an increase of the fundamental frequency of the acoustic wave, in addition to an intensity increase, although the characteristics of the resonant part remain unchanged.

Another inevitable characteristic of the oscillating systems illustrated in Fig. 17 is the unpredictability of the phase of the generated signal, once the sustain phase has been reached. Since the waveform (p(t) used to stimulate the system is partially chaotic, and in any case it does not

Amended specification, page 15

signals in transit along the functional blocks of the system uncontrollable. This makes the search for multiple sounds produced by this type of synthesis slow and difficult. On the contrary, a system with no feedback between resonator and excitation, such as the system shown in Fig. 2, enables to modify the numerical parameters of the three functional blocks (9), (11), (12) in a completely independent way, without impairing the good operation of the system as a whole. This allows obtaining a larger variety of sounds than the one obtained by means of a feedback loop system with equal complexity. ~~The current literature proposes, as e.g. in US patent 5,587,548, an alternative technique which is known as commuted synthesis, based on excitation wavetables and resonant filters, being the latter used to simulate the acoustical behaviour of an instrument's linear and passive part, in such a case, with an adequate sampled sound's analysis and optimization, a good compromise is found between the necessary amount of memory for the wavetables and the necessary computational power to implement the physical - mathematical algorithm which corresponds to the instrument's resonant parts.~~

The system of Fig. 3 shows a sequence of operations performed on the signal produced by the sinusoidal oscillator (14). The type and order of the operations are only one of the possible realisations used to generate a waveform sufficiently rich in harmonic components and provided with a suitable time evolution, in any case, some of the functional blocks of the system, such as the delay (24) and the non-linear function (26), derive from mathematical models of wind instruments known in the literature, without the need of using them. The originality of the system mainly consists in the adaptation of an undersized oscillator with status variables for non-stationary operational

conditioning by developing the functional blocks (30) and (32) of Fig. 4, in order to make the oscillator robust to the variations of the parameter F^2 of the block (29).

With reference to Figures 5 and 6, the originality derives from the development of the generator (34) to obtain pleasing random frequency variations in real time. Assuming the factor (33) as constant, that is to say assuming the absence of the low frequency oscillation of the sequence δf, the latter assumes a new random value at every period of the sinusoidal sequence VAR1. The result is a statistic uniformly distributed

modify the wavelength of said harmonic sequence with an oftenness which is proportional to said sinusoidal sequences' frequency.

Claim 25 (new) A method as described in claim 22, wherein said generation of an aleatory sequence (NOISE) step includes generating a random sequence, processing said random sequence by means of a loop containing delay lines and a rate limiter, and processing said rate limiter's output to obtain said aleatory sequence (NOISE).

Claim 26 (new) A method as described in claim 22, wherein said generation of an aleatory sequence (NOISE) step includes generating a random sequence and processing said random sequence by means of a loop containing delay lines and a rate limiter, being said rate limiter controlled by said periodic sequence (RATE).

Claim 27 (new) A method as described in claim 22, wherein said harmonic sequence and aleatory sequence processing step through a linear resonator consists in supplying said harmonic sequence and aleatory sequence into a closed loop composed by a delay line and linear filters, and extracting from said closed loop and sequence which represents the church organ flue pipes' synthesized sound.

Claim 28 (new) An electronic device for church organ flue pipes' sound synthesis comprising:

a harmonic component generator (9) to synthesize a main harmonic sequence (10),

a signal generator to synthesize a periodic sequence (RATE),

a noise generator (11) to synthesize an aleatory sequence whose slope is limited accordingly to the time progression of said periodic sequence (RATE).